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A Robotic System for Automated Handling of Ceramic Pucks

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A ROBOTIC SYSTEM FOR AUTOMATED HANDLING OF CERAMIC PUCKS

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I. INTRODUCTION

A process is being developed at Lawrence Livermore National Laboratory (LLNL) for immobilization and ultimate disposal of legacy nuclear materials. A Ceramification System Test Facility (CSTF) is being built at LLNL, while the actual Plutonium Immobilization Plant (PIP) will be built at Savannah River Site (SRS). The materials are formed into ceramic-based pucks in what is called the First Stage Immobilization (FSI) process. The FSI puck handling system will provide automatic conveyance of pucks through several process steps beginning with removing the "green" pucks from the forming press, loading and unloading the pucks into/from a sintering furnace, and ending with loading the sintered pucks into transport cans for removal from the CSTF glovebox. It will eliminate several potential operator hazards arising from operating machinery within the glovebox, reduce operator exposure to radiation, reduce the chance of damaging pucks during handling and increase the throughput of the system. Ancillary equipment is also being developed and integrated with the puck handling system to determine the mass and geometric properties of both the green and sintered pucks.

Although the CSTF is intended to demonstrate equipment that is prototypical of plant systems, significant differences exist between the envisioned plant and the LLNL CSTF with respect to their respective puck handling systems. LLNL and SRS both recognize this disparity, and although the CSTF puck handling system will not be plant prototypic in overall form, it will, however, be useful in addressing several plant-relevant puck-handling issues. Thus, the CSTF puck handling system will provide both short-term benefits for operation of the CSTF itself at LLNL, and support an overall project goal of demonstrating plant prototypic equipment for the SRS facility.

II. PRELIMINARY DEVELOPMENT

Initial steps in developing the puck handling system were to establish the functional and performance requirements, and to define the interfaces with other CSTF equipment. Functional requirements include:

Press Unloading

- Remove the "green" pucks from the press
- Weigh each green puck
- Measure each green puck's thickness and diameter
- Load the green pucks into the tray stack in the sintering furnace

Furnace Unloading

- Remove the sintered pucks from the tray stack in the sintering furnace
- Weigh each sintered puck
- Measure each sintered puck's thickness and diameter
- Load the sintered pucks into transportation containers for removal from the CSTF

Performance requirements include:

- Eliminate or minimize damage to pucks from handling
- Do not damage other equipment
- Remove pucks from the press rapidly enough to prevent significant delays in the press cycle
- Weigh each green and sintered puck to the nearest 0.1 gram
- Measure each green and sintered puck's thickness and diameter to ±0.005 in.

The puck handling system will interface physically and by signals with the puck press, the sintering furnace, and the puck weighing/measuring system. It will also interface by signals with the overall CSTF control system.

III. EQUIPMENT SELECTION

Equipment selection was performed in parallel with development of the press, furnace and glovebox geometry, as well as the ancillary equipment selection. Following preliminary determination of the glovebox envelope, press geometry and furnace geometry, several automation strategies were reviewed for suitability to the application. Several models of articulated multiaxis robots, cylindrical robots, SCARA-style robots and

Cartesian robots were evaluated. The Cartesian style was chosen for several reasons:

- Its overall geometry fits best within the glovebox envelope
- Its usable work envelope is greater than the others within the glovebox envelope
- The modularity of the system enables it to be easily optimized for the specific application
- The Cartesian geometry simplifies path prediction and collision avoidance with the glovebox or other equipment
- Individual components can more easily be replaced in-situ in case of failure
- Cartesian systems are cost effective for large work envelopes and light payloads

Having established the system configuration, methods of actuation were then evaluated. They included servopneumatic, belt drive and screw drive. A major criteria in selecting the method of actuation was to maximize the actuator stroke relative to its overall length, since a large workspace is required within the confines of the glovebox. Servopneumatic actuator technology is relatively new, and initially seemed to be a desirable option; they are relatively cheap (provided a compressed air source is already available), quick and have high payload capacity. Although they have an apparently long stroke for a given overall actuator length, it was found that physical constraints imposed by the servopneumatic control system negate that advantage. The stroke-to-overall length ratio is further lessened with the addition of the integral linear transducer module. Although an external linear transducer can be used, its implementation is mechanically complex and generally undesirable for a glovebox application. Additionally, servopneumatic systems degrade in resolution as stroke lengths are increased, and the stroke lengths required for the CSTF resulted in unacceptable servopneumatic resolution. Most of the advantages of a servopneumatic system are irrelevant to the CSTF application, since the pucks constitute a relatively light payload, extremely rapid motion is not required, and they offer no advantage in stroke-to-overall length ratio.

Screw drive and belt drive systems were then evaluated. Although both are capable of providing satisfactory performance, screw drive systems can be configured with a reverse parallel drive, offering the best stroke-to-overall length ratio, and were selected for the puck handling system. Although screw drive systems are speed-constrained in long stroke applications, maximum speeds are within target parameters for the stroke lengths required by the CSTF. Screw drive actuators are available in enclosed modules that, while not absolutely sealed, offer high resistance to particulate intrusion. This is an important feature, since screw drives cannot tolerate high levels of particulate contamination such as might occur in the ambient glovebox environment of the CSTF, especially near the press. An additional step that can be taken to protect the screw is to purge the actuator interior, creating a slight pressure differential that resists the influx of particulates. Screw drives can be driven by stepper or servo motors, and both motor types can be configured to operate in dry, inert atmospheres. Motor selection was, therefore, determined by the dynamic requirements of the system. Brushless servo motors were selected to meet performance and environmental requirements.

IV. EQUIPMENT DESIGN

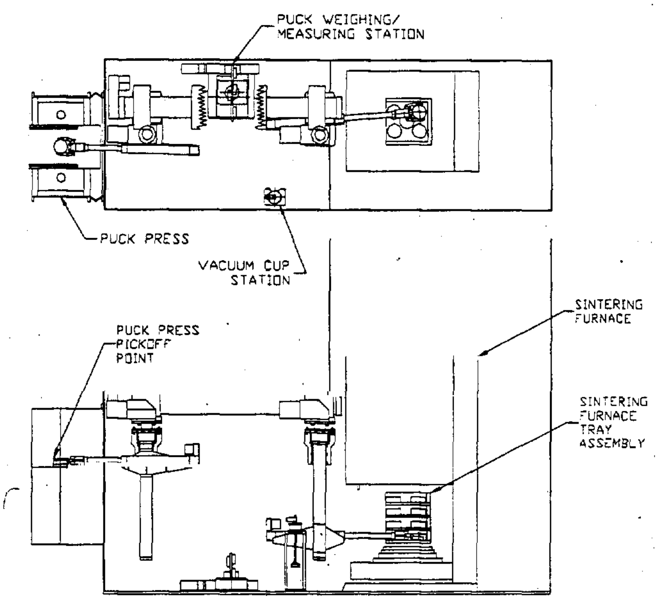

Illustration 1. Furnace Glovebox Layout with 4-axis Puck Handling System. (The single vertical column and attached components are shown in both the press pickoff position and the furnace tray dropoff position.)

The puck-handling system was custom designed so that it could reach its extreme target points (the press and the furnace trays), possess a large work volume, and fit within the glove box envelope. Its first axis is a horizontal screw drive linear actuator, which is attached to the glove box ceiling. A rotary joint is mounted to the horizontal actuator slide. The vertical column, also a screw drive actuator, is attached at its top end to the rotary joint. The last axis is another horizontal screw drive actuator, mounted to the vertical actuator slide, which serves as the extension joint to reach into the puck pressand sintering furnace tray stack.

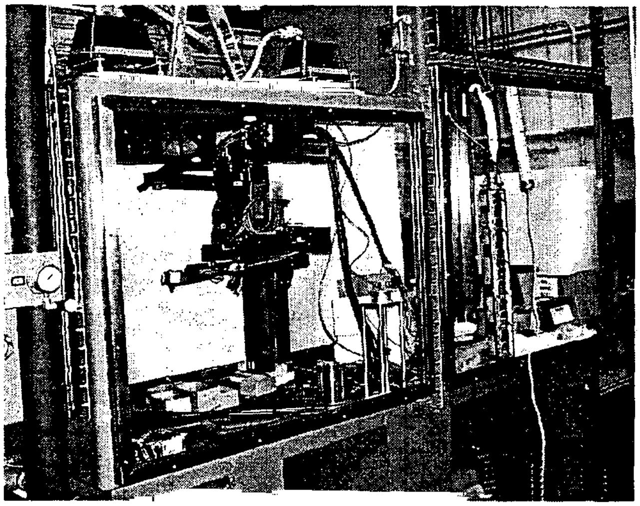

Illustration 2. Puck Handling System Being Installed in Furnace Glovebox

Custom gripper fingers were designed to mate with a commercially-available gripper. The physical constraints within the sintering furnace track assembly required a gripper design that was capable of approaching and retreating from a puck from the side, rather than from overhead, yet also does not collide with the tray walls when fully opened. Additionally, the sintering process reduces puck diameter from 3.5" to approximately 2.7", so the gripper was designed to accommodate that range of diameters. The furnace trays are composed of a refractory material, and are moderately fragile. Since the vertical actuator drive is non-compliant, it is conceivable that damage to the furnace trays could be incurred while loading the pucks due to variations in tray height. These variations can be expected to occur as a result of thermal cycling of the trays, variations in dimensions of specific trays at tray changeout, and variations in tray assembly position due to backlash in the sintering furnace mechanism. To mitigate this, vertical compliance was built into the gripper wrist, allowing up to 1/2" vertical variation in tray position.

V. ANCILLARY EQUIPMENT

A. Puck Weighing/Measuring Station

Puck weight, thickness and diameter will be routinely measured in the CSTF so that the measured parameters can be correlated to variations in other process parameters and to off-normal events. The puck will be weighed using a commercially-available balance with an RS-232 serial communications port for control and data collection. Puck thickness and diameter will be measured using laser displacement sensors. Non-contact measurement methods were evaluated to minimize the possibility of damage to the relatively fragile green pucks. It was found that ultrasound sensors could not reliably yield measurements to meet the performance specifications. Laser micrometers typically have resolutions much greater than that required for the CSTF (on the order of 5-100 μm), and Class II (eyesafe) systems are available with adequate depths of field to accommodate the range of measurements that will be taken. A unit was tested with green (white) and sintered (gray) pucks, and it was found that the diffuse reflectivity of both puck forms is well within sensor requirements for reliable measurements.

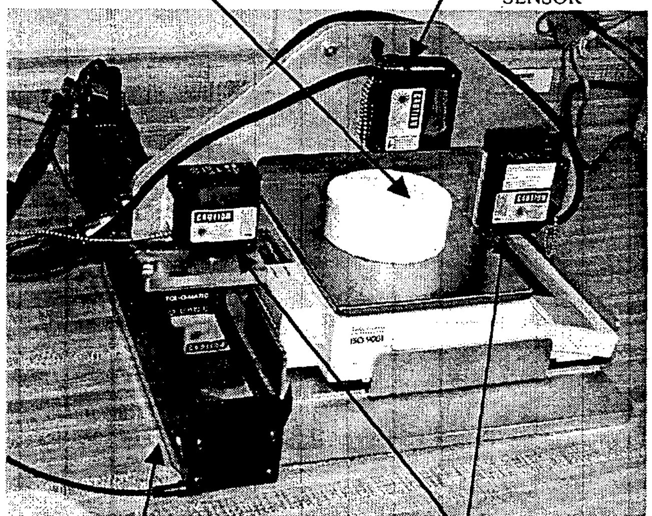

Illustration 3. Puck Weighing/Measuring Station

An overhead laser micrometer is used to measure the puck's thickness, which is calculated as the difference of the sensor-balance platform distance and the sensor-puck distance. A set of opposed laser micrometers are used to measure its diameter, which is calculated as the overall laser sensor span minus the two measured sensor-puck distances. To guarantee that the puck's diameter, rather than a chord is being measured (due to variations in puck placement), the laser array is mounted to a linear actuator. Once a puck has been placed on the balance platform, the laser array scans across the middle section of the puck. The maximum calculated "chord" distance among the measurements taken constitutes the puck's diameter. This method also allows several thickness measurements to be taken across the puck's face if desired.

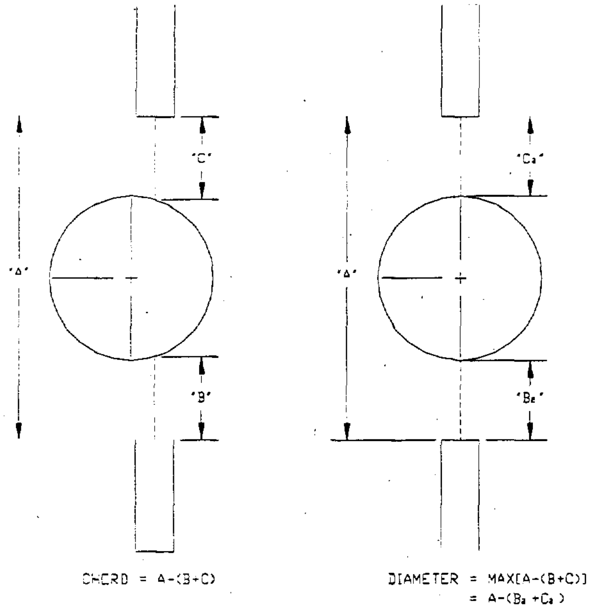

Illustration 4. Laser Micrometer-Based Measurement of Puck Diameter

B. Vacuum Tool

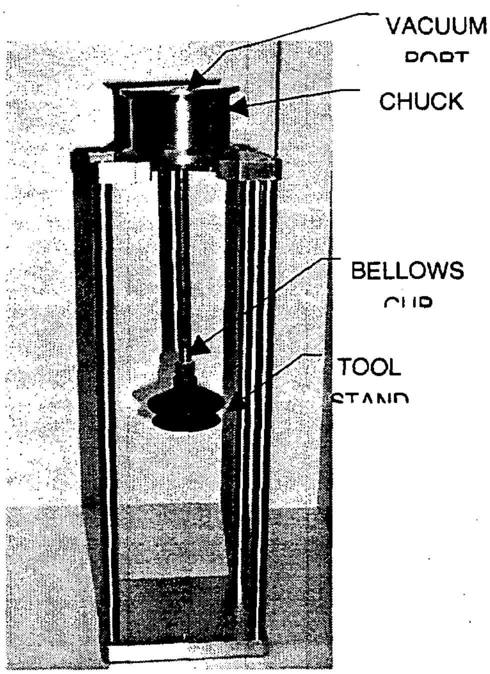

Illustration 5. Vacuum Tool and Stand

The last step in processing each puck is loading it into a transfer can. Since the gripper is designed to handle pucks from the side, rather than from the top, a vacuum tool was designed to enable the system to lower pucks down into transfer cans. At the top of the tool is a round chuck that is designed to mate with the gripper. Chamfers on the top and bottom of the chuck aid in vertical alignment during gripper engagement, and preclude vertical slippage subsequently. A bellows vacuum cup is fixed to the bottom of a tube extending from the chuck. A port on top of the chuck is connected to a vacuum supply via a coiled hose. To transfer a puck from the weighing/measuring station, the puck handler first grasps the chuck and removes the tool from its stand. The vacuum cup is placed over the puck and vacuum is applied. The tool/puck is then positioned over the transport can and lowered into it. The chuck itself does not enter the can cavity, since it is being grasped from the side by the gripper. To avoid collisions between the puck and can (or pucks previously placed in the can), the puck is held slightly above its target height, and vacuum is shut off. Leakage at the vacuum cup lip results in a gentle descent of the bellows until the puck rests on the substrate. The tool is then removed and returned to its stand.